Health implications of chimney-stoves in Mexico and Central America

Víctor Ruiz and Omar Masera

Cookstove Innovation and Testing Laboratory (LINEB)
Institute for Ecosystems Research and Sustainability (IIES), National University of Mexico (UNAM)

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IAP impacts from chimney stoves

What we know?

- There is an interest on the part of several countries to have clean fuels, more efficient devices and generate positive impacts on the quality of life of users (health and economy).
- It is recognized that access to clean cooking is a complex issue.
- There is not only one option of fuel or device for clean cooking, it requires a range of fuel combinations (biomass + LPG + solar + ...), use of more efficient devices and changes in usage practices.
- LPG is not a real or long-term solution (LPG is a finite fuel and requires large government subsidies).
- There are deficiencies in the standard protocols for evaluating devices used for cooking, specifically stoves with chimneys used in Latin America. In this way it is not possible to know the air quality inside the kitchen.
IAP impacts from chimney stoves

- Fugitive emissions, or the percentage of total emissions that leak into the kitchen, from chimney stoves are poorly characterized.
- Due to a lack of measurements, WHO Guidelines assumed that 25% (±10) of the total emission entered the kitchen (WHO, 2014).
- Using these default values in a simulation model, wood burning vented stoves did not meet any of the WHO Air Quality Guidelines or interim targets for indoor air.
- Similarly the ISO International Workshop Agreement (IWA) placed these stoves in Tier level 1 for indoor emissions of PM$_{2.5}$.
- The current measurements show that Mexican chimney stoves achieve WHO and ISO benchmarks, and that the default values do not reflect the performance of these stoves.
Objectives

- To measure fugitive PM$_{2.5}$ and CO emissions rates and fractions ($f$) associated to plancha-type chimney-stove models widely disseminated in Mexico and Central America.
- To parameterize with regional field data the Single Zone Model (WHO, 2014) to estimate indoor air pollutants concentration from Chimney stoves. In-field parameters measured include kitchen volume, air exchange rates and cooking time.
Experimental: Double hood for measuring fugitive (indoor) emissions and chimney emissions rates.

Chimney-stoves tested:
- Patsari
- ONIL
- Ecostufa
- Mera-Mera
Double Hood
Was used to simultaneously measure chimney and indoor emission rates from chimney-stoves

Stoves Tested
Four models of chimney-stoves were tested

- Ecostufa
- ONIL
- Mera-Mera
- Patsari

Medina et al., 2017.
The single-zone Box model used to derive WHO Guidelines was used to predict kitchen concentrations of PM$_{2.5}$ and CO resulting from indoor cookstoves emissions (WHO, 2014). The model uses the following equation:

$$C_t = \frac{Gf}{\alpha V} (1 - e^{-\alpha t}) + C_o (e^{-\alpha t})$$

Where,

$$C_t = \text{Concentration of pollutant within the kitchen at time } t \text{ (mg m}^{-3}\text{)};$$

$$G = \text{Emission rate (total emissions) (mg min}^{-1}\text{ or g min}^{-1}\text{);}$$

$$g_{In} = \text{Indoor emission rate (mg min}^{-1}\text{ or g min}^{-1}\text{);}$$

$$g_{Ch} = \text{Chimney emission rate (mg min}^{-1}\text{or g min}^{-1}\text{);}$$

$$f = \frac{g_{In}}{g_{In} + g_{Ch}} \text{ measured in the lab}$$

$$G = g_{In} + g_{Ch} \text{ measured in the field}$$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchen volume (V)</td>
<td>m$^3$</td>
<td>41</td>
<td>20</td>
<td>5</td>
<td>97</td>
</tr>
<tr>
<td>Cooking time (t)</td>
<td>min</td>
<td>259</td>
<td>123</td>
<td>60</td>
<td>480</td>
</tr>
<tr>
<td>Nominal air exchange rate (α)</td>
<td>h$^{-1}$</td>
<td>60</td>
<td>13</td>
<td>36</td>
<td>90</td>
</tr>
</tbody>
</table>
Results: Fugitive emissions from Plancha-type stoves

<table>
<thead>
<tr>
<th>Parameter</th>
<th>n</th>
<th>Chimney</th>
<th>Fugitive</th>
<th>Fraction of overall</th>
<th>Chimney</th>
<th>Fugitive</th>
<th>Fraction of overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONIL</td>
<td>15</td>
<td>52(32)</td>
<td>2.1(1.3)</td>
<td>0.05(0.03)</td>
<td>594(332)</td>
<td>12(12)</td>
<td>0.02(0.02)</td>
</tr>
<tr>
<td>Ecostufa</td>
<td>15</td>
<td>75(52)</td>
<td>3.5(1.9)</td>
<td>0.06(0.04)</td>
<td>931(588)</td>
<td>5(3)</td>
<td>0.01(0.01)</td>
</tr>
<tr>
<td>Mera-Mera</td>
<td>15</td>
<td>76(47)</td>
<td>2.4(1.6)</td>
<td>0.03(0.02)</td>
<td>1244(543)</td>
<td>20(16)</td>
<td>0.01(0.01)</td>
</tr>
<tr>
<td>Patsari</td>
<td>15</td>
<td>50(21)</td>
<td>3.9(2.1)</td>
<td>0.07(0.03)</td>
<td>1645(965)</td>
<td>11(11)</td>
<td>0.01(0.00)</td>
</tr>
<tr>
<td>All stoves</td>
<td>60</td>
<td>63(41)</td>
<td>3.0(1.8)</td>
<td>0.05(0.03)</td>
<td>1104(743)</td>
<td>12(12)</td>
<td>0.01(0.01)</td>
</tr>
</tbody>
</table>

Mean (standard deviation)

Fugitive emissions of PM\(_{2.5}\) and CO much lower than previously estimated WHO defaults - approximately 5% and 1% of overall emissions, respectively.
### Results: Modeled indoor air concentrations

<table>
<thead>
<tr>
<th></th>
<th>Particulate matter PM$_{2.5}$ (μg m$^{-3}$)</th>
<th>Mean (SD)</th>
<th>Median</th>
<th>10%</th>
<th>90%</th>
<th>Percent meeting Annual WHO guideline</th>
<th>ISO indoor emission</th>
<th>Carbon Monoxide (mg m$^{-3}$)</th>
<th>Mean (SD)</th>
<th>Median</th>
<th>10%</th>
<th>90%</th>
<th>Percent meeting 24-hr WHO guideline</th>
<th>ISO indoor emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONIL</td>
<td></td>
<td>10(6)</td>
<td>9</td>
<td>5</td>
<td>17</td>
<td>99%</td>
<td>58%</td>
<td>3</td>
<td>0.06(0.04)</td>
<td>0.05</td>
<td>0.02</td>
<td>0.10</td>
<td>100%</td>
<td>4</td>
</tr>
<tr>
<td>Ecostufa</td>
<td></td>
<td>17(10)</td>
<td>15</td>
<td>9</td>
<td>28</td>
<td>96%</td>
<td>17%</td>
<td>3</td>
<td>0.02(0.01)</td>
<td>0.02</td>
<td>0.01</td>
<td>0.04</td>
<td>100%</td>
<td>4</td>
</tr>
<tr>
<td>Mera-Mera</td>
<td></td>
<td>12(7)</td>
<td>10</td>
<td>5</td>
<td>20</td>
<td>99%</td>
<td>48%</td>
<td>3</td>
<td>0.10(0.06)</td>
<td>0.09</td>
<td>0.04</td>
<td>0.16</td>
<td>100%</td>
<td>4</td>
</tr>
<tr>
<td>Patsari</td>
<td></td>
<td>19(11)</td>
<td>17</td>
<td>9</td>
<td>31</td>
<td>94%</td>
<td>13%</td>
<td>3</td>
<td>0.05(0.03)</td>
<td>0.05</td>
<td>0.02</td>
<td>0.09</td>
<td>100%</td>
<td>4</td>
</tr>
<tr>
<td>All stoves</td>
<td></td>
<td>15(9)</td>
<td>13</td>
<td>7</td>
<td>25</td>
<td>97%</td>
<td>30%</td>
<td>3</td>
<td>0.06(0.04)</td>
<td>0.05</td>
<td>0.02</td>
<td>0.11</td>
<td>100%</td>
<td>4</td>
</tr>
<tr>
<td>LPG</td>
<td></td>
<td>4(2)</td>
<td>3</td>
<td>2</td>
<td>7</td>
<td>100%</td>
<td>98%</td>
<td>4</td>
<td>0.15(0.009)</td>
<td>0.14</td>
<td>0.07</td>
<td>0.26</td>
<td>100%</td>
<td>4</td>
</tr>
</tbody>
</table>

Fraction of homes meeting WHO guidelines much higher and ISO indoor emissions tiers are 3-4
Chimney stoves tested are ranked in Tiers 3 and 4.

Black circles represent simmering phase and white circles represent a mean of cold and hot start in a WBT test for each stove.
Model output distributions of PM$_{2.5}$ concentrations

- Chimney-Stoves tested in Lab
- ONIL
- Ecostufa
- Mera-Mera
- Patsari
- LPG

- WHO AQG Annual concentration PM$_{2.5}$, IT-1 (35 µg/m$^3$)
- Average Chimney-Stoves in simulated kitchen, mean 24hr (µg/m$^3$)
- Average Chimney-Stoves tested in Lab, mean 24hr (µg/m$^3$)
- WHO AQG Annual concentration PM$_{2.5}$, (10 µg/m$^3$)
- ONIL, geometric mean
- Ecostufa, geometric mean
- Mera-Mera, geometric mean
- Patsari, geometric mean
- LPG, geometric mean

WBT tests meet WHO IT1 guidelines
Model output preliminary validation of PM$_{2.5}$ concentrations

Range validation for LPG stove

Range validation for Patsari stove

WHO AQG Annual concentration PM$_{2.5}$, II-1 (35 µg/m$^3$)

WHO AQG Annual concentration PM$_{2.5}$, (10 µg/m$^3$)

Patsari, geometric mean

LPG, geometric mean
Chimney emissions between building (CFD simulation)

Figure 2. Pollutant plume using iso-surface of concentration (C) of 1 μg/m³ for emission rate of 40 mg/min and contour of pollutant concentration with distance X and height Z in the center of the plume.

Figure 3 shows the distance between buildings for emission concentration to decrease to 1 μg/m³ at the breathing height of the individual for different chimney emissions rates. As emissions rates for plancha-type stoves range between 50 and 76 mg/min (Table 1), stoves plumes would decrease to 1 μg/m³ at an average of approximately 93 m for the Patsari, 96 m for the ONIL, 136 m for the Ecostufa, and 136 m for the Mera-Mera, with an average of 115 m for all chimney stoves.
Out concentration did not achieve 4 µg/m³ So, the air quality meet the AQG (WHO).

**Chimney stoves achieve the WHO IT1**
Conclusions

- Fugitive emissions from plancha-type chimney-stoves are on average 5% for PM2.5 and 1% for CO, much lower than defaults in WHO Guidelines (WHO, 2014).
- The associated kitchen pollutant concentrations resulting from these fugitive emissions are estimated to be on average 17 ± 12 µg/m3 for PM$_{2.5}$ and 0.06 ± 0.06 for CO, suggesting that the stoves meet the WHO AQG Annual Interim Target I for PM2.5 and the 24-hr AQG for CO.
- Using the IWA Tier System for indoor emission rates, the chimney-stoves tested belong to Tier 4 for CO and 3-4 for PM$_{2.5}$. Therefore they should be classified as “clean” regarding health benefits.

Limitations

Re-infiltration from the chimney to the kitchen and/or infiltration from chimneys from other houses is not considered here, but is part of the larger analysis and journal publication.
To access the full report and for any comments please contact:

Victor Ruiz - vruiz@cieco.unam.com

Omar Masera – omasera@gmail.com
Our team and facilities
La Red Latinoamericana y del Caribe de Cocinas Limpias (RLCCL) celebrará del 12 al 14 de marzo de 2019 el 3er Foro Regional en la Universidad del Zamorano, Honduras. El objetivo del evento es intercambiar experiencias, discutir e identificar los principales obstáculos y oportunidades para una mayor promoción y comercialización de dispositivos y combustibles de cocción más limpios en la región, además de crear sinergia y colaboraciones entre los diversos actores. El Foro integra las siguientes actividades:

1. Plenarias
2. Sesiones temáticas paralelas: a) Tecnología e innovación, b) Normas y estándares, c) Mercados Sostenibles, d) Políticas públicas, e) Combustibles alternos y f) Uso, adopción e impactos
3. Sesión de carteles
4. Exhibición y demostración de dispositivos

Dirección de contacto: fororlccl2019@gmail.com

Bases para enviar resúmenes:

a) Resumen de 350 palabras, Arial 12 puntos, debe incluir objetivo, métodos y resultados
b) La fecha límite para envío de resúmenes es el día 10 de febrero de 2019; los resultados de los resúmenes aceptados será el 18 de febrero.

c) Se dará prioridad a los mejores resúmenes para otorgar apoyo económico por la asistencia al evento.

El 3er Foro de la RLCCL es financiado por el Proyecto Profogones del BID-LAB, la Fundación Vida de Honduras, ETHOS (Engineers in Humanitarian Assistance) de Oregon, EELU y el Clúster de Biomass combustibles Sólidos de México.

Dirección Universidad Zamorano: Apartado Postal 93, Km 30 carretera de Tegucigalpa a Danlí, Valle del Yeguare, Municipio de San Antonio de Oriente, Honduras.
To access the full report and for any comments please contact:

Victor Ruiz - vruiz@cieco.unam.com

Omar Masera – omasera@gmail.com
Summary and Main Findings

- Fugitive emissions from four widely disseminated woodburning Plancha-type chimney stoves were measured to estimate indoor air pollution impacts.

We found that:

- Plancha-type chimney stoves vent on average $95\% \pm 3\%$ and $99\% \pm 1\%$ of total PM$_{2.5}$ and CO emissions out of the kitchen, respectively.

- IAP concentration levels resulting from these stoves, are estimated to be on average $17 \pm 12 \mu g/m^3$ for PM$_{2.5}$ and $0.06 \pm 0.06 \mu g/m^3$ for CO.

- As a result, all the Plancha-type chimney stoves tested comply with WHO Air Quality Guidelines (AQG) Annual Interim Target I for PM$_{2.5}$ and the 24-hr AQG for CO, respectively.

- Equivalent ISO indoor emission tiers for these stoves would be 3-4

- The fraction of fugitive emissions is much lower than WHO defaults, and substantial benefits would be expected from stoves with chimneys.

Note: ± values are standard deviations.